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Evaporator with stacked flat tubes possessing two opposite fluid boxes

The invention relates to an evaporator for the exchange of heat between an airflow and a refrigerant fluid with the latter passing from the liquid state to the gaseous state, especially for air-conditioning the passenger compartment of a motor vehicle, comprising a tube bank consisting of a single row of flat tubes stacked alternately with corrugated spacers holding the tubes spaced apart from one another by a distance <u>d</u> and the corrugations of which define passages for the airflow in the direction of the width of the tubes, the two ends of each tube communicating respectively with two fluid boxes situated at opposite ends from one another with respect to the said tube bank, in such a way as to define a journey in at least two passes for the refrigerant fluid in the evaporator.

Such an evaporator is said to be a "frontal circuitry" type evaporator, as opposed to an evaporator with "U circuitry" in which the refrigerant fluid circulates in U-shaped tubes the two branches of which communicate with respective chambers of a single fluid box. The number of passes is the number of individual journeys made by the refrigerant fluid, along a tube from one fluid box to the other, between the inlet and the outlet of the evaporator. This may be an odd number, if the inlet and the outlet are situated respectively on the two fluid boxes, or an even number, if they are situated on the same fluid box. Depending on the technology used, the fluid boxes may be affixed, that is to say assembled to the tubes, or not affixed, that is to say formed from the same pieces as the tubes.

The frontal circuitry exhibits the advantage, by comparison with the U-circuitry, of reducing the length of tubes traversed by the refrigerant fluid, for a given number of tubes used at each pass, thus reducing the loss of pressure head and the corresponding heating of the refrigerant fluid, as well as the separation of the liquid and gaseous phases. The thermal exchange with the airflow is therefore enhanced by virtue of a lower and more uniform refrigerant-fluid temperature between the various tubes of a single pass.

The frontal circuitry also allows economical manufacture of the evaporator, with tubes which are all identical allowing advanced automation of its manufacture.

The object of the invention is to propose dimensional characteristics which are suitable for optimizing the performance of this type of evaporator, more particularly when the number of passes is 4 or 6.

The invention especially envisages an evaporator of the type defined in the introduction, and provides for its dimension l in the said direction to lie between 20 and 55 mm and for the distance d to lie between 4.0 and 7.6 mm.

The proposed dimension in the direction of the airflow ensures a reduced bulk of the evaporator in this direction, and a saving of material. It tends, however, to reduce the surface area for exchange between the two fluids. This tendency is compensated for by the choice of a distance d which is also reduced. The combination of these two dimensional characteristics makes it possible to reconcile the reduction in bulk and the saving in material which are mentioned above with a level of performance comparable to that of the evaporators usually used for air-conditioning the passenger compartment of motor vehicles.

Optional characteristics of the invention, which are complementary or alternative, are set out below:

- the total thickness of a tube lies between 1.0 and 2.7 mm.

- the wall thickness of a tube lies between 0.2 and 0.45 mm, and between 0.2 and 0.7 mm in the case of the nose of the tube.

- the internal thickness of a tube lies between 0.6 and 1.8 mm.

- the half-period of corrugation of the spacers lies between 1.0 and 1.8 mm.

- the wall thickness of the spacers lies between 0.05 and 0.1 mm.

- the tubes and the fluid boxes are in the form of a stack of pouches each formed from two sheet-metal plates stamped into cup shape, the concavities of which are turned towards one another and which are brazed together so as to be leaktight at their periphery, each pouch defining one of the said tubes and featuring, at each of its ends, an increased thickness so as to define a segment of fluid box.

- the fluid boxes are independent components featuring apertures through which penetrate the ends of the tubes, the latter being brazed so as to be leaktight to the edge of the apertures.

- each tube is formed from two stamped sheet-metal plates which are brazed together for leaktightness along their lateral edges and for stiffening in intermediate regions projecting towards the inside of the tube.

- each tube is formed from two stamped sheet-metal plates which are brazed together so as to be leaktight along their lateral edges, the tube being stiffened by an insert brazed onto the inner faces of the plates.

- the tubes are extruded tubes.

- the tubes are formed from metal sheets which are folded and closed by longitudinal brazed joints.

- at least one fluid box is formed from two elements delimiting an internal volume, one of which features the said apertures, and at least one affixed internal partition separating the said internal volume into different chambers each of which communicates with one subset of the tubes.

- at least one fluid box is formed from a manifold plate featuring the said apertures, and of at least two tank-shaped elements interacting with the manifold plate, each over a part of the extent of the plate, so as to delimit respective chambers each of which communicates with a subset of the tubes.

- at least one fluid box is formed from at least one stamped sheet-metal element defining, on either side of a fold line, a manifold plate featuring the said apertures and a tank which are brought edge to edge by folding and brazed together so as to delimit a chamber of the fluid box.

The characteristics and advantages of the invention will be set out in more detail in the description below, by referring to the attached drawings.

Figures 1 and 2 are partial sectional views of an evaporator.

Figures 3 to 7 are graphs showing the influence of the dimensional characteristics on the functioning of an evaporator.

Figures 8 to 10 are views in longitudinal section of different embodiments of an evaporator.

Figure 11 is a view in perspective of a component intended for the production of an evaporator fluid box.

Figure 1 is a partial view in section of the tube bank of an evaporator of the type to which the invention is applied, showing two adjacent flat tubes 1, in transverse section, and the corrugated spacer 2 interposed between them. A few of the dimensions which the invention aims to optimize are indicated here, namely the width $\underline{l}$ of the tubes, that is to say the dimension of the evaporator in the direction of flow of the airflow, represented by the arrow F1, the distance $\underline{d}$ between the tubes, fixed by the corrugations of the spacer, the total thickness $\underline{E}_e$ of a tube, that is to say its bulk in the direction of the stack of the tube bank, the wall thickness $\underline{e}_1$ of a tube, and the internal thickness $\underline{E}_i$ of a tube, equal to $\underline{E}_e - 2\underline{e}_1$.

Figure 2 is a partial side view of a spacer 2, showing its corrugated profile substantially in sinusoidal shape. The distance $\underline{d}$ between the two planes P containing the corrugation crests is seen again here. The wall thickness $\underline{e}_2$ of the spacer, and its corrugation half-period $\underline{p}/2$, are also seen.

According to the invention, the abovementioned dimensions ideally lie in the intervals as below:

$$20 \text{ mm} \leq \underline{l} \leq 55 \text{ mm}$$
$$4.0 \text{ mm} \leq \underline{d} \leq 7.6 \text{ mm}$$
$$1.0 \text{ mm} \leq \underline{E}_e \leq 2.7 \text{ mm}$$
$$0.2 \text{ mm} \leq \underline{e}_1 \leq 0.7 \text{ mm}$$
$$0.6 \text{ mm} \leq \underline{E}_i \leq 1.8 \text{ mm}$$
$$1.0 \text{ mm} \leq \underline{p}/2 \leq 1.8 \text{ mm}$$
$$0.05 \text{ mm} \leq \underline{e}_2 \leq 0.1 \text{ mm.}$$

Figure 3 shows the variation in the heat-exchange capacity of an evaporator envisaged by the invention as a function of the distance $\underline{d}$, other things being equal, and keeping the air throughput constant. It is seen that the maximum effectiveness under these conditions is reached for a value of 4 mm. However, a

reduction in the distance d increases the loss of pressure head of the airflow and consequently reduces the air throughput for a given speed of the blower. This is why the values chosen are at least equal to this apparent optimum, that is to say that they lie between 4.0 and 7.6 mm.

The wall thickness e_1 is chosen so as to ensure an appropriate resistance to pressure and to corrosion, without excessive consumption of material.

The graph of Figure 4 shows the variation in the heat-exchange capacity of an evaporator as a function of the internal thickness e_i of the tubes. When this thickness value is low, this results in a loss of pressure head of the refrigerant fluid and a rise in its temperature impeding the thermal exchange. In contrast, a substantial thickness has the effect of a lower speed of the fluid, limiting the heat exchange with the walls of the tubes. The chosen range provides optimized results.

The graphs of Figures 5 and 6 respectively represent the variation in the thermal-exchange capacity of an evaporator and that of the loss of pressure head which it causes the airflow to undergo, as a function of the half-period p/2 of the spacers, the air throughput being kept constant.

In Figure 7, the curve depicted by the symbol ○ and that depicted by the symbol ▼ represent the variation in the loss of pressure head suffered by the air in an air-conditioning apparatus as a whole, as a function of the throughput, respectively for p/2 = 1.4 mm and p/2 = 1.7 mm. The curve depicted by the symbol ■ represents the variation in the back-pressure produced by the blower as a function of the throughput. The intersection of a curve of loss of pressure head and of the curve of back-pressure represents the operating

point for the air of the evaporator/blower combination. Thus the air throughput passing through the evaporator is obtained, and the performance delivered by it is deduced therefrom. By repeating the approach for various values of p/2, the optimal value for a given blower is determined. By proceeding thus for various blowers and various air-conditioning boxes, the values proposed according to the invention were arrived at.

The tubes 1 shown in Figure 1 are each produced by the brazing-together of two plates 1a and 1b, stamped so as each to form two marginal longitudinal ribs 1c and a multiplicity of intermediate longitudinal ribs 1d. The marginal ribs 1c of one of the plates are brazed to the marginal ribs of the other plate so as to achieve leaktightness of the tube with respect to the outside. Each intermediate rib 1d of a plate is brazed to a rib 1d of the other plate so as to stiffen the tube and to delimit circulation channels 1e for the fluid within the tube. The intermediate ribs 1d can be replaced, wholly or partly, by stiffening projections which do not extend from one end to the other of the tube and which do not delimit circulation channels.

Figure 8 represents, in longitudinal section, an embodiment of an evaporator 10 according to the invention, in which the tubes and the two fluid boxes are formed by a multiplicity of pouches 11 which are stacked together from the left to the right of the figure, each consisting of two sheet-metal plates stamped into the shape of cups 12 and 13. The latter are identical to each other and have their concavities turned towards one another, i.e. respectively to the right and to the left. Each cup exhibits a peripheral edge situated in a vertical plane, and the peripheral edges of the two cups forming a pouch are assembled together so as to be leaktight to the fluid by brazing, in order to

delimit the internal volume of the pouch. Each cup includes an upper region 14 and a lower region 15 of a greater depth than that of the intermediate region 16. The regions 16 of two associated cups together constitute one tube of the tube bank. The upper regions 14 of the same cups define between them an individual volume 17 forming part of the internal volume of the corresponding pouch and communicating with the upper end of the tube. The set of the regions 14 forms an upper fluid box 18, each individual volume 17 communicating with at least one adjacent volume 17, via apertures 19 formed in the bottom of the cups, so as to form one chamber of the fluid box. Likewise, the lower regions 15 of the cups define between them individual volumes 20 communicating with the lower ends of the tubes, and together form a lower fluid box 21 including at least one chamber. The two fluid boxes have to possess at least three chambers in total in order to ensure a circulation of the fluid in at least two passes. In the example illustrated, the inlet 22 and the outlet 23 for the fluid are provided respectively on the lower fluid box and on the upper fluid box, in such a way that the number of passes is an odd number and at least equal to three. The corrugated spacers 2 are brazed to the outer faces of the intermediate regions 16 of the cups 11, 12.

Figures 9 and 10 are views similar to Figure 8, relating to evaporators including tubes 1 produced independently of the fluid boxes, for example by assembling cups similar to the cups 12, 13 of Figure 8, but not including the regions 14 and 15 of increased depth, or in the form of extruded tubes, or, in a known way, by folding sheet metal and forming longitudinal brazed joints.

The upper fluid box 31 and the fluid box 32 of the evaporator 30 of Figure 9 each comprise a manifold plate 33 featuring a multiplicity of apertures 34 into which penetrate the ends of the tubes 1 and equipped with a peripheral rim 35 turned away from the bank of tubes. The upper manifold plate serves as a cover for a tank-shaped piece 37, the peripheral edge 38 of which is brazed to the rim 35, the two pieces delimiting the internal volume of the fluid box. Within this internal volume is found another tank-shaped piece 39 the peripheral edge 40 of which is brazed to the plate 33. The lower manifold plate 33 serves as a cover common to two tank-shaped pieces 41 and 42 which are mutually juxtaposed in the direction of stacking of the bank of tubes. The peripheral edges 43, 44 of the tanks 41, 42 are brazed to one another in their area of mutual contact and, moreover, to the peripheral rim 35 of the plate 33. The tank 39 separates the internal volume of the fluid box 31 into two chambers 45 and 46 situated respectively inside and outside the tank 39, and communicating respectively with a central subset of the tubes and with the rest of them. The tanks 41 and 42, with the manifold plate 33, respectively delimit two chambers 47 and 48 of the lower fluid box, which communicate respectively with two subsets of the tubes following each other in the direction of stacking of the tube bank. The fluid penetrates into the chamber 45 through an aperture 49 formed in the side walls of the tanks 37 and 39, and circulates from top to bottom in the central subsets of the tube so as to reach, in part, the chamber 47 and, in part, the chamber 48. From them, it travels the other tubes from bottom to top and arrives in the chamber 46, which it leaves through an aperture 50 of the piece 37. The circulation of the fluid in the evaporator thus takes place in two passes.

The evaporator 50 of Figure 10 possesses a lower fluid box 32 identical to that of Figure 9 and which will not be described again. The upper fluid box 51 features a structure similar to that of the box 31, with a manifold plate 33 identical to those of the boxes 31 and 32, and three tanks 52, 53, 54, instead of two in the case of the box 32, which are juxtaposed in the direction of stacking and delimiting respectively with the plate 33 chambers 55, 56 and 57. The fluid penetrates into the chamber 55 through an aperture 58 provided in the tank 52, and circulates from top to bottom in a first subset of tubes so as to reach the chamber 47 of the lower box. From there, it circulates from bottom to top in a second subset of tubes so as to arrive in the chamber 56. It leaves the latter by running from top to bottom through a third subset of tubes which lead it into the chamber 48. It finally runs from bottom to top through a fourth and final subset of tubes so as to pass from the chamber 48 to the chamber 57 after which it leaves the evaporator through an outlet aperture 59 provided in the tank 54. The circulation takes place here in four passes.

Figure 11 represents a stamped sheet-metal piece 60 intended to be associated with a bank of tubes and of spacers such as those represented in Figures 9 and 10, by forming at least a part of a fluid box. The piece 60 comprises two regions 61 and 62 situated respectively to right and to left, as seen in the figure, of a horizontal line L, and stamped respectively upwards and downwards with respect to the horizontal plane containing the line L, so as to form, on the one hand, a tank, and, on the other hand, a manifold plate pierced by apertures 63 and equipped with a peripheral rim 64. By a rotation of 180° about the line L, as indicated by the arrows F2, the plate 62 comes to fit

into the tank 61, the rim 62 coming into contact over its entire perimeter with the peripheral wall 65 of the tank, to which it is brazed so as to be leaktight. The piece thus fashioned may by itself constitute a single-chamber fluid box, or several similar pieces can be juxtaposed so as to form a fluid box with multiple chambers. An inlet or outlet aperture 66, as the case may be, for the fluid is provided in the peripheral wall 65.

Needless to say, in the case in which the internal volume of a fluid box is delimited by two elements such as a manifold plate and a tank-shaped piece, and subdivided into two or more chambers, this separation can be achieved in a known way by virtue of transverse partitions.

Another means, known in itself, for stiffening the tube consists in inserting into it an insert brazed to the inner faces of the plates, for example a corrugated insert brazed by its corrugation crests.